Geoelectrical Assessment of the Subsurface by Vertical Electrical Sounding (VES) in Abyei, West Kordofan State, Sudan2022 AD

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Abstract:

Resistance methods were used as an aid to sitting water supply boreholes, and geoelectrical methods were applied to draw the cross sections of resistivity underground in the Abyei Region and around it. At Baggara Basin, the target of the study is to use the resistivity data and interpret geoelectrical soundings to study the aquifer conditions for hydrogeological purposes. So, in order to determine the thickness of the geologic layers and the distinction between soft-rock sandy aquifers and clayey material by electrical sounding measurement, the study area is covered by measurements of about 68 points of vertical electric sounding (VES). The locations of all VES points have been fixed by GPS. All measurements were taken with the SAS-1000 terrameter from ABEM (Sweden). The soundings were performed using the symmetrical Schlumberger electrode arrangements with a maximum half-separation of AB/2 = 900 –1000 m. This is generally adequate for a penetration depth of more than 300 m in the study area. The quantitative interpretation of the VES curves is performed using a computer program (IPI2 WIN). In this study, a model for each field curve is proposed based on the type of curve and its resistivity variation. Interpretation of these soundings indicates that the thickness of the sediments in the area ranges from a few meters in the north, northeast, and southwest to 400 m, in which the drilled boreholes (e.g., Gulei and Dayer wells) are located. Furthermore, zones with high yield potential have been determined in this research based on the resistivity data. The formation factor ranges from 1 to 6, with an average of 3 being used to classify the three facies. (from fine to medium to coarse).

Keywords: vertical electrical sounding; geoelectric section; description of the thickness of the geologic layers and the excellence between soft-rock sandy aquifers and clayey material.

التقييم الجيوكهربائي تحت السطح بواسطة السبر الكهربائي العمودي في أبيي ولاية غرب كردفان – السودان 2022م

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المستخلص:

تم استخدام أساليب المقاومة كعامل مساعد في حفر آبار إمداد المياه ، كما تم تطبيق الأساليب الجيوكهربائية لرسم المقاطع العرضية للمقاومة تحت الأرض في منطقة أبيي وحولها. الهدف من الدراسة في حوض البقارة هو استخدام بيانات المقاومة وتفسير السبر الجيوكهربائي لدراسة ظروف الخزان الجوفي للأغراض الهيدروجيولوجية. لذلك ، من أجل تحديد سمك الطبقات الجيولوجية والتمييز بين طبقات المياه الجوفية الرملية الصخرية الناعمة والمواد الطينية ، عن طريق قياس السبر الكهربائي ، تم تغطية منطقة الدراسة بقياسات حوالي 68 نقطة من السبر الكهربائي العمودي. تم تحديد مواقع جميع نقاط السبر الكهربي العمودي بواسطة نظام تحديد المواقع . تم أخذ جميع القياسات باستخدام جهاز المقاومة ساس 1000 السويدي. تم إجراء عمليات السبر باستخدام ترتيبات قطب شلمبرجير المتناسقة مع أقصى نصف فصل من AB / 2 = 1000- 900 متر. هذا مناسب بشكل عام لعمق اختراق يزيد عن 300 متر في منطقة الدراسة. يتم تنفيذ التفسير الكمي لمنحنيات السبر الكهربي العمودي باستخدام برنامج كمبيوتر (IPI2 WIN). في هذه الدراسة ، تم اقتراح نموذج لكل منحنى مجال بناءً على نوع المنحنى وتغير مقاومته. يشير تفسير عمليات السبر هذه إلى أن سمك الرواسب في المنطقة يتراوح من بضعة أمتار في الشمال والشمال الشرقي والجنوب الغربي إلى 400 متر ، حيث توجد الآبار المحفورة (على سبيل المثال ، آبار غولي ودايز). علاوة على ذلك ، تم تحديد المناطق ذات القدرة الإنتاجية العالية في هذا البحث بناءً على بيانات المقاومة. يتراوح عامل التكوين من 1 إلى 6 ، مع استخدام 3 في المتوسط لتصنيف السحنات الثلاث. (من ناعم إلى متوسط إلى خشن).

Introduction:

Geo-electrical methods are applied to map the resistivity structure of the underground and hydrogeological systems because they enable, for example, distinguishing between fresh and saltwater based on the electrical resistivity of rock and fluid content. The resistivity of coarse-grained, well-consolidated sandstone saturated with fresh water is higher than that of unconsolidated silt of the same porosity saturated with the same water. (1). Through the Vertical Sounding Curve, all VES curves are found to depict somewhat deep and multi-layered earth, with typically dropping types for the intermediate strata. To indicate rising resistivity values, most curves have a propensity to climb near the end of the maximum separation. The average resistivity of the region is low (5–50 m). The most prevalent varieties are QHA and KQQ 2(). since all curves indicate the existence of thick sediments, no basement trends are expected. It is known how the presence of groundwater affects the resistivity of the water-bearing strata. But in this study, locating resistivity zones that are connected to the existence of high-quality groundwater is the main goal of the sounding technique.

Materials and methods:

Site description and geology:

The study areas are located in West Kordofan State and at sites in East Darfur State and the Republic of South Sudan. between latitudes 9° 00 and 12° 00 N and longitudes 23° 00 and 30° 00 E. The study area and the surrounding districts have recently gained political and economic importance as they include reasonable hydrocarbon discoveries and potential. In addition to the livestock wealth and agricultural as well as forestry potential, many unpaved roads can be followed to different towns and villages in the area. And the annual rainfall ranges between 300 and 700 mm per year on average (3). The area is characterized by a savanna climate ranging from poor in the north to rich in the southern parts. The land in the study area is rich and fertile. General geology and hydrogeology setting: Generally, the topography of the area is flat, with topographic elevations ranging from more than 450 m (A.M.S.L.) in the north to about 430 to 380 m southward. The slope of the area trends south. The geological units are the superficial deposits and Umm Ruwaba formation, the Nubian sandstone, and the basement complex (4).

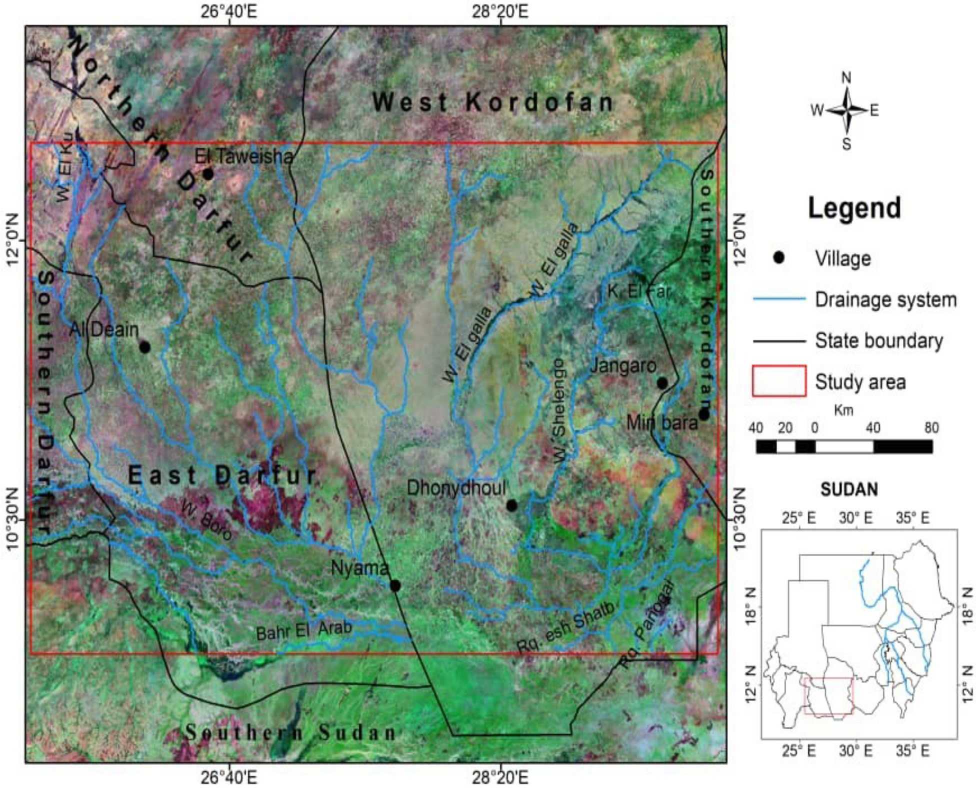


Figure (1) Location Map of the Study area.

Materials and Methods:

The idea of equivalence, which implies that a measured sounding curve is related to multiple physically equivalent models that may differ greatly, is fundamental to the modeling and understanding of vertical electric sounding curves. According to its interpretation, there is relatively high resistivity, recent sand, clay, and clayey sands on top of a layer of relatively low resistivity, superficial dryness, and recent sand in the area.

Geoelectrical resistivity surveys:

For examining the groundwater in the area, geoelectrical resistivity techniques are a popular and effective geophysical exploration method. The research region is measured at around

24 vertical electric sounding locations (VES). To the north, south, and center of the area being researched, three profiles were constructed (Fig. 2). C C, AA, and B B These diverse cross-sections provide crucial information on the thickness of distinct aquifers. All available geological information, including lithological log descriptions of the boreholes, was used to generate these geoelectrical sections. The resistivity values serve as the foundation for the geological explanation. Curve-type analysis, statistical evaluation of the resistivity values of certain geological formations, and reconnaissance-style observations can all have an impact. The resistivities and thicknesses of the strata, as well as the sounding curves of the profiles, were determined from the interpretation of the geoelectrical section data in the research region (Fig. 2).

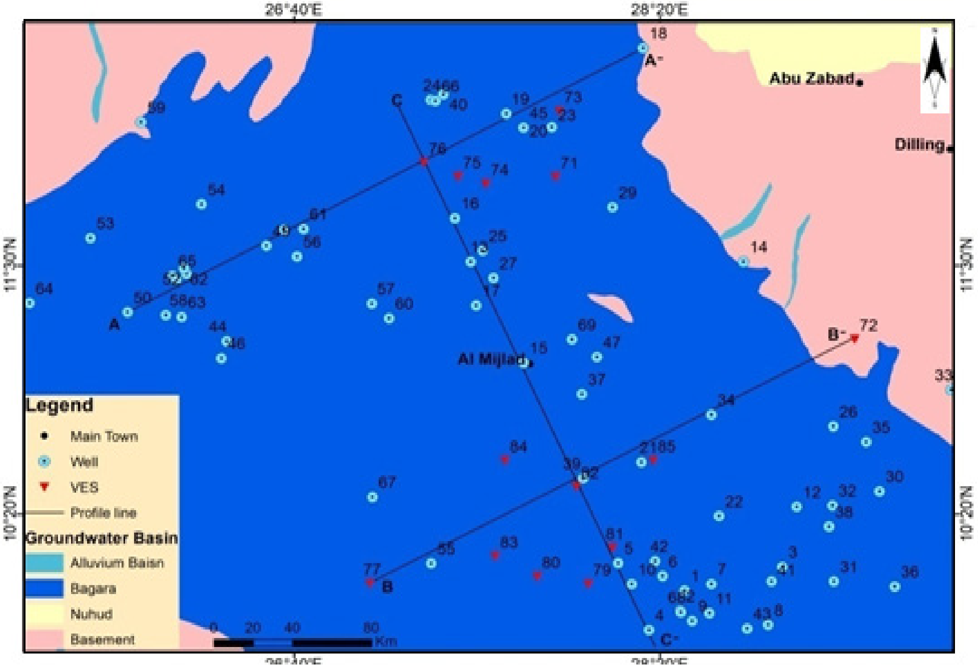


Figure (2): A geological map and profiles of the geoelectrical sections.

Source: Water resources Assessment and Development project in Sudan (WADS).April 1989.

Interpretation of vertical electrical sounding (VES):

A computer program, such as the IPI2WIN version software, is used to do the quantitative interpretation of the VES curves. In this work, a model is put forth for each field curve depending on the type of curve and the resistivity fluctuation of the curve. A theoretical curve is created by the program on iteration computers based on an input model, and it is adjusted repeatedly until it closely resembles the field curve. The possibility of thin blind zones and the common occurrence of equivalence and anisotropy in multi-layered soils serve as general limitations on the quantitative interpretation approach.(5) This refers to the fact that, unless proper control or calibration using borehole information is applied, different models can be explained by the same curve. The identified hydrogeological units, such as the Um Ruwaba formation and superficial deposits that are covered by the investigated region, are taken into consideration when classifying the vertical electrical sounding (VES) readings (6). The variations in resistivity are attributed to the formation. The results of the geoelectrical section in the study area were interpreted depending on the values of resistivities and thicknesses of layers and the sounding curves of the profiles (Fig. 2) (7). Are presented as follows:

I.Geoelectric section along profile AA$^-$:

The geoelectric section passes along three boreholes and includes VES numbers 39, 38, 86, 5, 78, 80, and 71 from the Shagadi in the southwest to Debbab Sharq town in the northeast direction of the investigated area. This section is constructed from different formations. The upper part of the section shows two layers consisting of superficial deposits and sandy clay, which are present between the points of VES 38–86 and Nibeig Borehole. The other part of the section with various resistivity values ranges from 5 to 20 ohms, while the thickness of these deposits ranges from 25 to 125 m, respectively. The lower part of the top layer shows sand, medium to fine, which has a resistivity ranging from 15 to 30 ohm.m. The thickness of this layer is about 225 m. It was found that the last layer is sandy clay with a medium resistance of about 13 ohms, up to a depth of 325 meters, as in the Nibeig well.

II. Geoelectric section along profile B-B´:

The two-type layer section was carried out between the Siheib borehole and Mashaga village, which is limited between points 33, 37, 35, and 42 and four boreholes. The first zone layers mixed with the superficial deposits composed of clay, sandy clay, and medium sand. The resistance of these layers ranges from 5 to 10 ohm.m, and the thickness reaches about 140 m.

III Geoelectric section along profile C-C´:

The geoelectric section extended between seven points of the VES (85, 47, 61, 86, 5, 78, and 80) and the Um Khair, Sitaib borehole between Dahlob southwest and Sitaib northeast. The first layer is mixed with the superficial deposits composed of sand and clay with sand lenses. The resistivity of this layer ranges from 13 to 20 ohm.m. The thickness of the deposit is increasing from the northwest to the center and exceeds three hundred seventy-five meters in the Maqbool borehole.

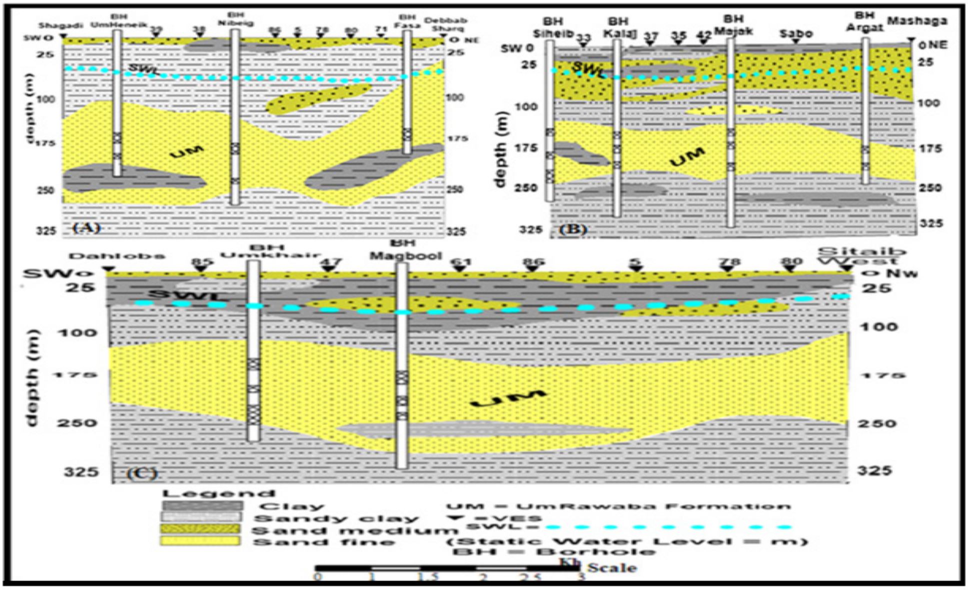


Figure (3):Stratigraphic demarcation using geoelectrical and lithology sections along
(A-A-, B-B-, and C-C-).

▼5 Um Sikean ▼33Al Jangai▼35Dayer South▼37 Maad elBagar
▼38 Al Hireika▼39Um Darees▼42 Mickeeinies▼47Antilla
▼61Jem elRaiee▼71 Abu Shara▼78 Angetu▼80Aghbash kokai
▼85 Kajjam▼86 kajam Faarragalla.

Logging of Geophysical Wells:

These measurements are made by lowering different types of probes into a borehole and electrically transmitting data in the form of either analog or digital signals to the surface, where they are recorded as a function of depth or distance along the borehole. The measurements are related to the physical and chemical properties of the rocks surrounding the borehole, the properties of the fluid saturating the pore spaces in the formation, the properties of the fluid in the borehole, the construction of the well, or some combination of these factors.(8).

Electrical Logging Interpretation:

The interpretation is based on empirical formulae that connect a porous formation’s real resistivity to its lithological characteristics, the interstitial water’s resistivity, and the amounts of water in the pores (9). Lithological determination is frequently performed by computer programs. To establish the following correlations between the various stratigraphic units in this region:

I, Siheib:

The static water level is measured at a depth of 44 m (Fig 3). According to electrical logs, the borehole is divided into three zones: the upper and second zones are made up of sand and a little clay and gravel, and the lower zones are made up of clay. Monitoring with gamma rays is used to measure the location of rock formations where clay minerals are formed, as clay minerals have great capabilities in the field of positive ion exchange, leading to a rise in their values that exceed 50. At the positive potential, there is an increase in the resistivity that exceeds 30 ohm.m. The second zone is made up of a sand layer mixed with a few clayey layers. These layers are separated by two aquifers (the upper and second), and the lower zone that is composed of clay indicates the dry zone.

II. Kalaj:

At this site, the results of electrical logs are divided into three zones. The upper zones are characterized by sand, and the second zone is made up of sandy clay. The resistivity of the formations in this zone shows an increase that reaches 25 ohms. The lower zone is covered by sticky clay, which reduces resistance values to 5 ohm.m. The static water level is measured at a depth of 44 m (Fig 4).

III.Radyia Majak:

In this borehole, a few clayey grains of sand and gravelly sands are presented in the lithological log. Sand is dominated by facies observed at different levels and separated by a clayey-gravelly sand layer. The static water level is recorded at 77 m (Fig 4). Depending on the electrical logs of the borehole and the resistivity of these zones, it is about 20 to 25 ohm.m. According to the interpretation of lithology and electrical logs, the third zone can be delineated as an aquifer.

IV. Um Khair:

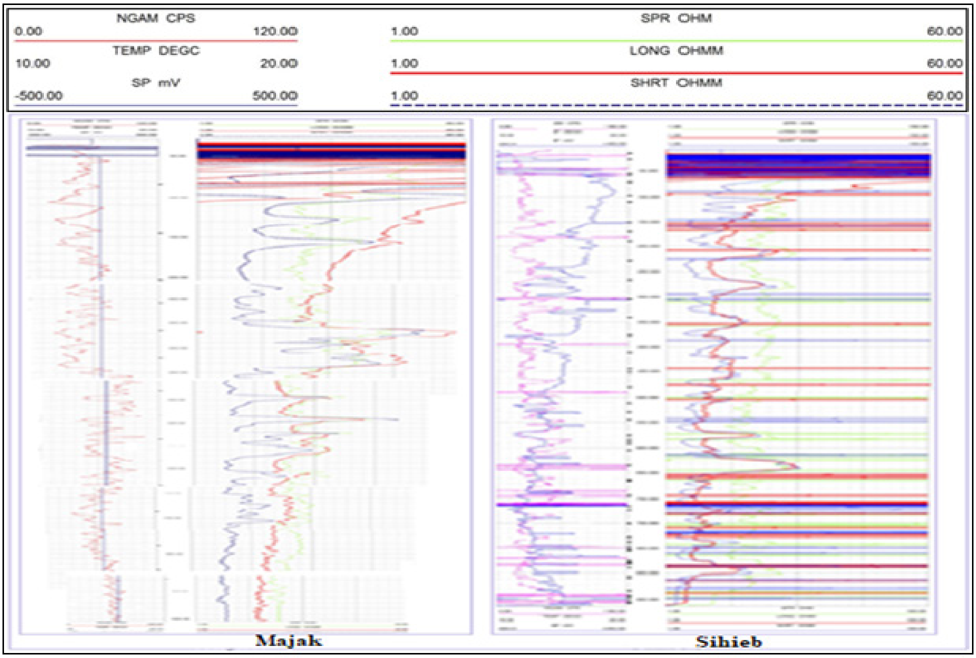
The lithological log in this borehole shows that sand and a few lenses of clay are present. The measured static water level is 48m (Fig 4). The formations in this zone exhibit an increase in resistivity that approaches 50 ohm.m. By using reference lithology and electrical logs, the last section, which extends from the well's end to a depth of 575 feet, is regarded as the major reservoir.

V.Magbool:

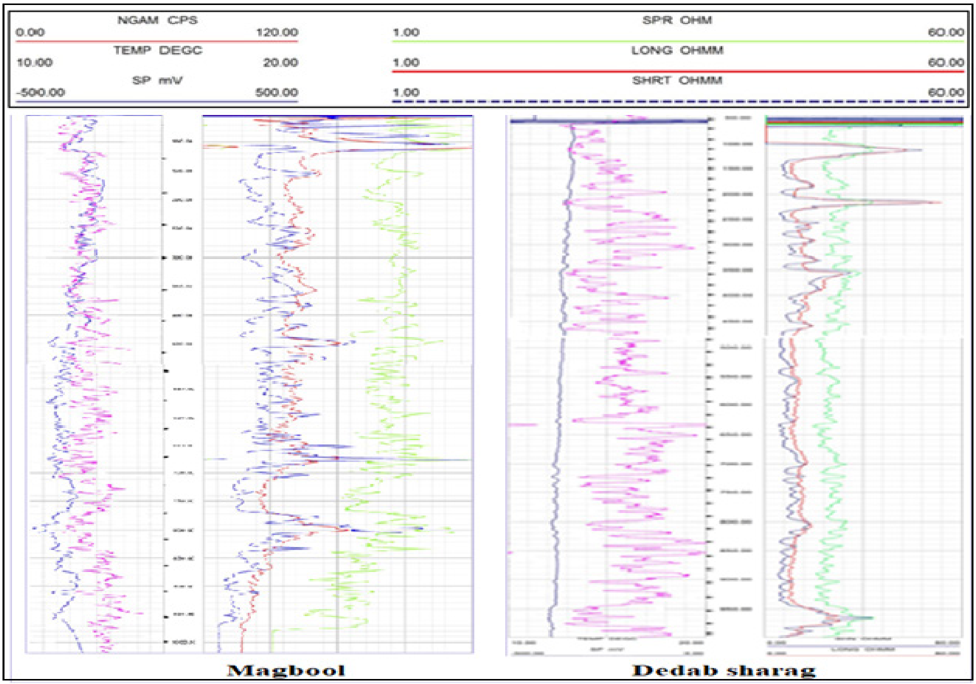
The static water level is measured at a depth of 44 m (Fig 4). At this site, the results of electrical logs are divided into three zones. The upper zones are characterized by sand, and the second zone is made up of sandy clay. The resistivity of the formations in this zone shows an average that reaches 15 ohm.m. The lower zone is covered by sticky clay, which shows a decrease in the resistivity values of 5 ohm.m.

VI.Debab Sharg:

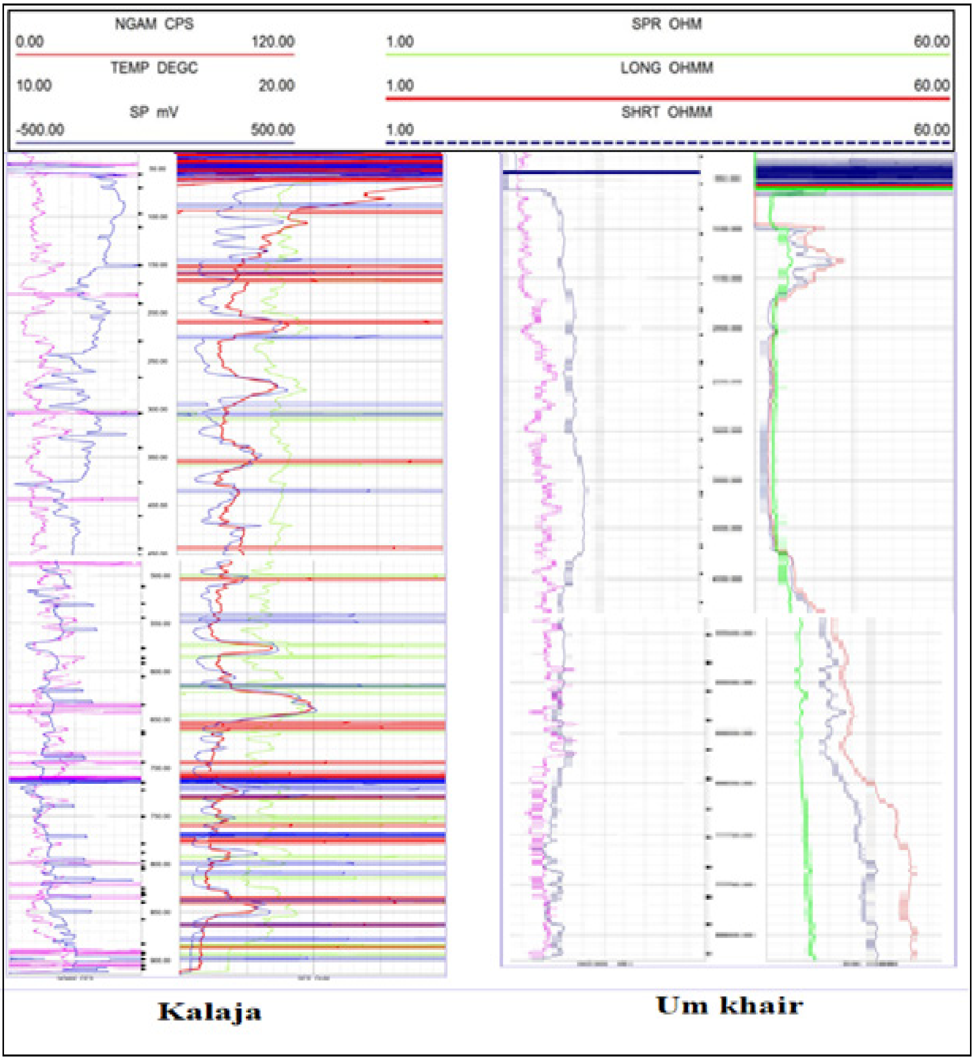
At these sites, different horizons, little sand, and sticky clay are observed in the electrical logs. The logs reflect alternative and intercalated sand and clay layers in the different zones. This borehole is penetrated by three superficial deposit formations: the Um Ruwaba formation, sticky clay, and sandstone. Digging depths have reached 1,000 ft. These layers are characterized by a low resistivity of about 8 ohm.m compared with the other layers in this zone. Moreover, decreased resistivity may be attributed to saline water. (Fig 4).



Majak **Sihieb**



Magbool **Dedab sharag**



Kalaja

Um khair

Figure (4) Geophysical well logging

Formation Factor Determinations by Well Logging Resistivity:

It is possible to take advantage of the aquifer resistance obtained from the electrical well logging in order to find the water resistance in the geological formation and then benefit from the electrical conductivity values obtained from the laboratory analysis. A summary of these techniques is found in “The Art of Ancient Log Analysis,” compiled by the Society of Professional

Well Log Analysts (1979). These values seem more suitable to be used as they are new to the site, and the measurements show that there may be local differences in groundwater resistance. In this work, a number of sites in the study area were used for electrical monitoring operations, and their electrical conductivity was measured. For laboratory samples, electrical conductivity measurements proved to be good. And the equation below can be used:

Formation factor (Fa) =Aquifer Resistivity)(Logging) ………. (1)
Water Resistivity

Water Resistivity = 10.000 (Factor) ………. (2)
Electrical conductivity (Lab)

The process begins with the SP log, which is used to determine the formation water resistivity (Rw), indications of lithology; next, the gamma ray log is introduced because of its use for the determination of porous zones. The porosity logs (acoustic and density) and that for the determination of the formation resistivity factor (Fa). All the above-mentioned coefficients were found in the field and in the laboratory using the above-mentioned equation, and the results were monitored as shown in the table below for the aquifers in the study area, upper and lower.

Location	Aquifer Resistivity (Ω-m) (Log(ging	Electrical Conductivity(µs/cm) Lab	Water Resistivity ((Ω-m	Formation factor ((Fa	Lithology
					Upper Aquifer-depth(50-140 (m
Dayer North	46	720	13.8	3	medium
KalagiEl-dood	50	690	14.5	3.5	medium
Majak	47	457	21.88	2.1	medium

Location	Aquifer Resistivity (Ω-m) (Log-(ging	Electrical Conductivity(µs/cm) Lab	Water Resistivity ((Ω-m	Formation factor ((Fa	Lithology
					Upper Aquifer-depth(50-140 (m
Suhiab	76	500	20	3.8	coarse
Almagbool	17	650	15.38	1.1	Fine
Alasker	21	594	16.8	1.7	Fine
Tafaha	40	684	14.6	2.7	medium
Dambaloya	25	450	22.2	1.14	Fine
Gulei	74	796	12.6	5.87	coarse
Um khair	87	541	18.48	4.7	coarse
Abugazala	23	320	31.25	1	Fine
Angoal	93	549	18.2	5	coarse
Malam	52	514	19.45	2.67	medium
Moglad	39	533	18.76	2.1	Fine
Al dibab	24	240	41.66	1	Fine
U. gomash	60	660	15.15	3.9	medium
U.garnjak	103	400	25	4.12	coarse

In the study area, the Upper Aquiferdepth (50–140 m):

In the study area, the lower aquifer depth (152400- m):

Location	Aquifer Resistivity (Ω-m) (Log-(ging	Electrical Conductivity(µs/cm) Lab	Water Resistivity ((Ω-m	Formation factor ((Fa	Lithology
					Lower Aquifer-depth(152-400 (m
Dayer North	20	720	13.8	1.4	Fine
KalagiEldood	38	690	14.5	2.6	medium

Majak	35	457	21.88	1.59	Fine
Suhiab	44	500	20	2.2	medium
Almagbool	21	650	15.38	1.5	Fine
Alasker	18	594	16.8	1.1	Fine
Tafaha	45	684	14.6	3	medium
Dambaloya	31	450	22.2	1.4	Fine
Gulei	67	796	12.6	5.3	coarse
Um khair	99	541	18.48	5.4	coarse
Abugazala	24	320	31.25	1	Fine
Angoal	63	549	18.2	3.46	coarse
Malam	55	514	19.45	2.9	medium
Talatat	24	520	19.23	1.2	Fine
Moglad	51	533	18.76	2.7	medium
Al dibab	25	240	41.66	1	Fine
U. gomash	65	660	15.15	3.7	medium
U.garnjak	55	400	25	2.1	medium

Upper Aquifer-(depth(50-140 m	Lithology Description	Formation factor ((Fa
	Fine	-1.5 1
	Medium	-3.5 2
	Course	-6 4

Lower Aquifer-depth(152-400 (m	Lithology Description	Formation factor ((Fa
	Fine	-1.5 1
	Medium	-3.5 2
	Course	-6 5

The Relationship between Water Resistivity and Quality:

In situ water-quality measurements concerning various ions and dissolved solids concentrations have been closely approximated using open-hole borehole geophysical logs. Analyses have revealed a strong relationship between water resistivity (as determined by logs) and dominant ion concentrations in granular formations sampled from a wide range of water quality. It was found that water resistivity was accurately determined by cross-plotting saturated formation resistivity (Ro), obtained from normal or lateral resistivity logs, against formation bulk porosity from neutron, density, or acoustic velocity logs (10). It was found that the resistivity of water is directly determined by the concentration of dissolved salts that are found in the water (11). If there is an ample amount of dissolved salts in the water, the water will have low resistivity. The opposite is also true. But there usually exists a strong correlation between water resistivity and ion concentration for the major ions present within a particular mass type (calcium carbonate, sodium chloride, etc.). Considering these investigations of formation factors and calculations of water resistivity in the study area.

Conclusion:

Through the geo-electrical models, the above ranges of resistivity are used to construct geo-electrical sections for each site. However, the main features in the study area of the interpreted models can be summarized as follows:

- The bulk of the sedimentary section is composed of low-resistivity sediments, generally clays or sands saturated with brackish water. The thickness of these sediments amounts to more than 200 meters.
- Medium resistivity horizons at upper levels are generally attributed to saturated coarse sands. These sandy bodies may be from upper perched aquifers which are generally discontinuous.
- Most of the VES curves and well logging charts indicate a relative rise in resistivity at a depth generally greater than 200 m. This is demonstrated clearly by several curves that represent the

top of a higher resistivity zone generally formed of sands saturated with freshwater. This resembles the target zone for this study.

✓ Based on all the findings made in the interpretation of the VES data and well logging and lithology, the thickness and values of resistivity of the aquifers indicate the medium potential for groundwater. Conclusively, the study area has a high potential for groundwater development.

Recommendations:

To improve the lifestyle in the study area, the main recommendation is to avoid water of low quality and not enough quantity. There are some recommendations for future groundwater studies for the study area.

1. From geophysical studies and borehole data, the study area is suitable for deep groundwater drilling.
2. Construct an effective network of observation wells to conduct proper pumping tests and hence estimate reliable aquifer parameters.
3. Water harvesting through the construction of dams and hafirs in main wadis, e.g. (Regaba ez Zaraga-Gulei area-Wadi Alghala) the area and the establishment of a pipeline network in the area adjacent to the surface water resource.
4. The geophysical logging should be carried out in the boreholes to demarcate the saturated layers and their water quality.
5. To obtain more accurate and reliable results, computer technology and the latest software for groundwater research are recommended.
6. Detail hydro geological studies should be conducted (especially in the southern part of the study area) to estimate the water budget and to design a proper water

management system in the study area, Therefore, we recommend making modelling the amount of pumping increases, and this depends on the urban and industrial development because the study area depends on direct pumping from the aquifer.

7. The economic activity can be changed from a mobile pastoral system to a stable agricultural system by replacing crops with high water needs with others that use less water for irrigation due to the availability of surface and groundwater resources in the area.

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